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DRYING POTATOES FOR FEED IN A DIRECT-FIRED, ROTARY DRIER. ECONOMIC FEASIBILITY OF THE PROCESS[1, 2]

PAUL W. EDWARDS, A. HOERSCH, JR., C. S. REDFIELD AND RODERICK K. ESKEW

This paper describes a method of converting white potatoes to stable form in which they may be conveniently stored, shipped and used for feed or as raw material for industrial fermentations.

The Bureau of Agricultural and Industrial Chemistry Circular AIC-209, "Producing Feed and Flour from White Potatoes with Steam Tube Driers," describes a method developed at the Eastern Regional Research Laboratory by which idle equipment in distilleries or other plants can be used. That process requires steam, which usually is not available at potato storage plants in sufficient quantities to operate steam tube driers.

[1] Accepted for publication December 13, 1951.

[2] Eastern Regional Research Laboratory, Philadelphia 18, Pa.
One of the Laboratories of the Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration, U. S. Department of Agriculture.

The method described in this paper uses a direct-fired, rotary drier. These driers are simple to operate and are widely used for drying farm crops and require no source of steam. In the northern states where potato storage facilities are available, potatoes could be dried from October 1 through May and forage crops or vegetable wastes (1) could be dried during the summer. This permits the use of the plant throughout a large part of the year and thus reduces the cost of making the products.

General Description of Process

The process consists essentially of the following steps: (1) Wash the potatoes; (2) grind them in a hammer mill; (3) continually mix the ground potatoes with some of the dried product; (4) dry the mixture in a direct-fired rotary drier; (5) screen the dried potato to remove the fines before recycling to the mixer; (6) then bag the remainder of the coarse material and all the fines as product.

Equipment Requirements and Details of the Process

It is assumed that the potatoes have an average moisture content of 80 per cent. It is also assumed that the potatoes will be delivered to the factory from an adjacent storage plant by means of an underground or totally enclosed screw conveyor; hence, no storage facilities are provided. The equipment is that required for a factory processing 62 tons of potatoes in 24 hours and producing 13.8 tons of feed containing 10 per cent moisture.

Washing: The potatoes are conveyed to the washer by a 9-inch screw conveyor equipped with a speed controller. A washer (3) such as that ordinarily employed in potato starch factories is well suited for this purpose. This consists of a U-shaped trough divided into sections and equipped with rotating paddles, which keep the potatoes in rapid motion and lift them from one compartment to the next, while water flows continually through the washer. The stones and much of the dirt settle to the bottom of the trough and are periodically removed by flushing. Stones must be removed to prevent damaging the hammer mill and pumps. A trough approximately 2½ feet in diameter and 25 feet long with four compartments will wash 62 tons of potatoes in 24 hours thoroughly.

Grinding: To reduce the potatoes to a form suitable for drying, they are ground in a hammer mill equipped with a screen having holes ⅜ inch in diameter. Ordinary blunt hammers may be used. One mill 6 inches wide by 12 inches in diameter driven with a 7½ horsepower motor should have sufficient capacity. The speed of the mill should be sufficient to give a hammer tip speed of approximately 6500 feet per minute. Much higher tip speeds may require a coarser screen to avoid too fine a product.

The ground potatoes are discharged into a 300-gallon wooden tank equipped with a slow-moving, paddle-type agitator, which prevents the solids from settling. This tank holds sufficient ground potatoes to operate the drier for nearly one-half hour and serves as a reservoir in case repairs must be made to the washer or hammer mill.

Mixing: To prevent the material from sticking to the drier or forming balls that cannot be satisfactorily dried, the moisture must be reduced to

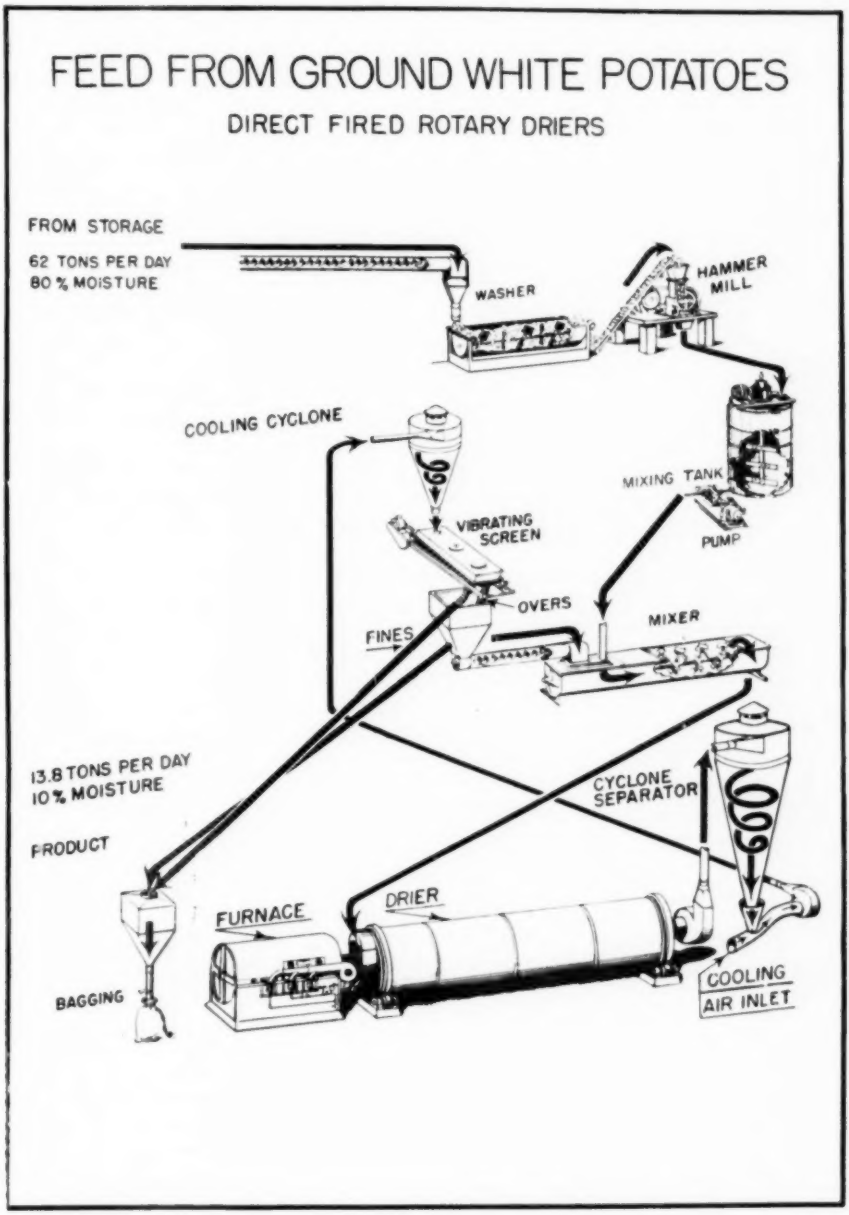

Fig. 1.—Diagrammatic sketch of equipment layout

approximately 42 per cent. This is accomplished by continuously recycling a sufficient quantity of the dried product and mixing it with the ground potatoes. Experience has shown that this cannot be satisfactorily accomplished, even with good mixing, in less than 4 minutes; a period of 6 or 7 minutes is preferable. With proper mixing and a sufficiently long retention time to permit the dried material to rehydrate, the mixed product when squeezed in the hand will form a ball that crumbles easily, and if dropped from a height of only 3 feet will break into small pieces. For the proposed factory a paddle-type mixer-conveyor 20 inches in diameter and 50 feet long is required. To conserve floor space, this mixer may be made in two sections, 20 and 30 feet long, respectively, with one section located above the other. A 10-horsepower motor is required to drive the mixer. The mixer-conveyor must be equipped with adjustable paddles so that a retention time of 6 to 7 minutes can be obtained. A variable-speed, positive-delivery pump of a type that will not further disintegrate the potatoes is required to convey the ground potatoes, and a screw conveyor with a speed controller is required for metering the dried product to the mixer-conveyor. These permit close control of the wet stock fed to the drier.

With potatoes and products containing 80 and 10 per cent moisture, respectively, the pump must deliver 5160 pounds of ground potatoes and the metering conveyor 6130 pounds of dry product each hour to the mixer-conveyor.

Drying: The drier used in our investigations was a small, commercial-size, multipass, oil-fired rotary drier, of the type commonly used to dry alfalfa. The rotating body, 16 feet long, is made up of three concentric cylinders, 2½, 5 and 7 feet in diameter, respectively. The inner cylinder is the combustion chamber. The oil burner is mounted at one end of this cylinder, and protrudes from the main body. The drying air, drawn in by an exhaust fan through openings adjacent to the burner, is heated by mixing with the products of combustion.

The material from the mixer-conveyor is carried to the top of the drier, where it falls into the screw feeder, which carries it into the drier. Here it meets the heated air and products of combustion and is carried by them through the annular spaces of the drier to an exhaust fan. The gases and dried product from this fan are delivered to a cyclone separator adjacent to the drier. The hot gases escape through the top of the separator, and the dried material falls through the bottom. Here a stream of cold air from another fan picks up the dried material and conveys it to a cooling cyclone separator. From the bottom of the second separator, the dried material falls into a vibrating screener.

Tests made with this drier, with an inlet gas temperature of 1200°F., produced a product that was not scorched and had a good potato odor. During this test, the feed rate used gave an exit gas temperature of approximately 210°F., and the product contained less than 10 per cent moisture. An inlet gas temperature of 1200° was about as high as could be obtained with our drier. It is possible that this material might be dried at higher inlet gas temperatures without scorching, and thus increase the capacity of the plant and reduce the cost of making.

Drying tests made in our drier gave over-all thermal efficiencies of nearly 80 per cent, which is good for a drier of this type.

Calculations based on our experience with the 7 x 16 feet multipass rotary drier show that a triple-pass rotary drier 8 x 24 feet will evaporate 4010 pounds of water per hour from potatoes prepared in the manner described, with an inlet gas temperature of 1200°F. A drier having this evaporative rate will dry 62 tons of potatoes having 80 per cent moisture to 13.8 tons of product at 10 per cent moisture in 24 hours. Presumably other properly designed driers of the rotary type, single or multiple-pass, could be employed.

The fans and cyclone separators in this drier must handle 7280 pounds per hour of dried material, weighing about 43 pounds per cubic foot, because of the recycling technique. The fan for the cooling system normally furnished on rotary alfalfa-type driers may not be large enough to convey this amount of dried material. The cooling fan on our drier did not have sufficient capacity to handle all the dried potatoes when the drier was operated at 1200°F. For these reasons, the drier manufacturer should be consulted regarding both fan and cyclone separator requirements for the cooling system. To prevent the production of a large amount of fines, and to reduce the possibility of dust explosions and fires initiated by foreign material striking the fan, it is recommended that the material be sucked rather than blown through the system. This can be accomplished by connecting both the hot and cold cyclone separator fans to the gas discharge side of the cyclone separators, which will require the use of air locks on the bottom of both cyclone separators.

Screening: The 100-mesh fines must be removed from the dried material which is recycled in order to reduce the possibility of having a dust explosion or fire. This is accomplished by removing all the 100-mesh fines from the dried material as it comes from the cooling cyclone separator. For the 62-ton plant, a vibrating screener equipped with a 100-mesh screen approximately 3½ feet wide and 8 feet long supported by a coarse backing screen should have sufficient capacity to handle 7280 pounds per hour of dried material.

The coarse material which goes over the screen falls into a hopper. Part of it is recycled by a metering conveyor to the mixer-conveyor. The remainder passes to the bagging bin, where it is combined with the fines from the screener and then is bagged as product and stored.

Costs

To have definite figures on all items entering into the cost calculations, a specific area for the plant was chosen. Aroostook County, Maine, was selected because of the large quantities of potatoes grown there and because of the shortage of feeds produced in that area. It is also reported that dairy cattle and poultry are being raised there in increasing numbers.

The following assumptions are made. The factory will be operated in conjunction with existing potato storage operations. Therefore, no charge for land, roads or railroad siding is included in the capital costs. Furthermore, no fees for storage of the raw potatoes are included in the costs. The building proposed is of wood construction. The plant will dry potatoes 24 hours a day, 6 days a week, from October 1 to May 31. Parts of the plant will operate from June 15 to August 31, drying clover or other forage crops. The factory will operate 210 working days on potatoes and 66

working days on clover. This is a total of 276 working days per year. Such a plant located in an area where vegetables are grown commercially could be used in summer for drying vegetable wastes.

The factory will produce 13.8 tons of potato feed containing 10 per cent moisture per 24-hour day. This production will require 62 tons of potatoes. On a yearly basis this plant can produce 2898 tons of feed from 12,999 tons of potatoes. The capital costs for this plant are shown in table 1, and costs to make potato feed are given in table 2.

TABLE 1.—*Capital costs*

Site preparation	$ 525
Building, wood frame construction, 50 x 65 ft. and 15 ft. high	25,350
Boiler, heating	530
Equipment, manufacturing	
Conveyor, screw, metering	2,700
Washer	1,030
Conveyor, flight	705
Hammer mill	835
Tank, wood and agitator	690
Pump, positive delivery	485
Conveyor, metering	655
Mixer-conveyor	3,840
Drier	18,325
Vibrating screen	1,730
Collecting hopper	260
Bagging head	130
Trucks, scales and small tools	265
Erection of equipment, manufacturing	7,910
Piping and ductwork	215
Erection of piping and ductwork	170
Heating installed	1,220
Light installed	725
Power installed	2,860
Freight on equipment	630
Office furniture and fixtures	515
Contingencies	9,265
Engineering fees	11,120
Total fixed capital	92,685
Working capital	18,540
Total Capital	$111,225

When cull potatoes are available at the plant for 25 cents per hundredweight, the cost to make a ton of product would be $52.59.

No general cost estimate of this type will exactly fit the conditions of any prospective manufacturer. With an understanding of the assumptions upon which the estimate is based, however, a manufacturer should be able to make a reasonable estimate of his own costs.

It should be emphasized that the capital costs given here and the

TABLE 2.—*Daily cost to make potato feed.*

Prime cost		
Raw materials	Nil	
Labor	$108.00	
Total		108.00
Indirect materials		
Bags	66.24	66.24
Factory overhead		
Indirect Labor		
Supervision	26.84	
Watchmen	1.88	
Office help	8.48	
Truck operator	10.00	
Total indirect labor		47.20
Indirect expense		
Insurance	1.68	
Taxes	6.72	
Interest, fixed capital	16.79	
Social security	2.16	
Workmen's compensation	1.60	
Unemployment insurance	4.66	
Depreciation	23.34	
Maintenance, repairs and renewals	20.15	
Vacation time	1.30	
Power	20.47	
Steam	.92	
Oil, fuel	50.16	
Water	7.75	
Gasoline	6.00	
Factory supplies	1.15	
Total indirect expense		164.85
Total factory cost		386.29
Interest on working capital	2.76	2.76
Administrative and general expense	26.25	26.25
Total cost to make		415.30
Production rate, tons per day	13.8	
Cost to make, dollars per ton	30.09	

cost per ton for producing the products are based on the use of a new building and the purchase and installation of new equipment.

ECONOMIC FEASIBILITY OF THE PROCESS

It is of prime importance to know whether that factory, when operated 8 months on potatoes and 2½ months on clover or other materials, can make a reasonable profit. This should depend on the feed value of dried potatoes as compared with corn, and will depend upon the price paid for cull potatoes. The following is an analysis of potato feed made at the Eastern Regional Research Laboratory by the process described.

	Per cent
Moisture	6.90
Protein (N x 6.25)	11.64
Fiber	2.41
Fat	.12
Ash	5.32
Carbohydrate (by difference)	73.61

Information compiled by Allender (*2*) on the feeding of dairy and beef cattle, lambs and swine showed that when dried potatoes were used as part of the rations to replace part and, in some instances, all the corn or other grains in the rations, the animals responded satisfactorily. In one experiment with lambs, one lot was fed dried cubed potatoes, which constituted the only concentrate in the ration. As compared with whole corn, the dried cubed potatoes fed alone produced 7 pounds more gain per lamb during the 84-day feeding period, and consumption of the cubed potatoes and alfalfa hay was lower per 100 pounds of gain, in comparison with the lot receiving corn. In this test, based on only one lot of lamb for 1 year, the cubed potatoes proved to be worth one-third more than whole corn.

Feeding tests (*4*) have shown that there was no effect on the live weight or the dressed weight of White Pekin ducks, marketed at 9 weeks of age, when 20 per cent of potato meal was substituted for 20 per cent of corn meal, 20 per cent of wheat standard middlings, or 10 per cent of corn meal plus 10 per cent of wheat standard middlings. Therefore, in 100 pounds of control ration containing 30 pounds of yellow cornmeal and 25.0 pounds of wheat standard middlings, 20 pounds of dried potato feed could be substituted for 20 pounds of corn meal, 20 pounds of wheat standard middlings, or 10 pounds of corn meal plus 10 pounds of wheat standard middlings. Thirty per cent of potato meal is probably the maximum amount that could be fed under these conditions, since there was some indication in one trial that when 30 per cent of potato meal replaced 15 per cent of corn meal plus 15 per cent of wheat standard middlings, the weight was slightly reduced. In these tests, there seemed to be no difference between the potato feed prepared at the Eastern Regional Research Laboratory and air-strip dried potato meal.

These data indicate that dried potatoes, corn, and corn meal are almost equal in value for the feeding of livestock.

Based on the assumption that dried ground potatoes are equal to corn as feed, table 3 gives the manufacturer's profit on the fixed investment ($92,685) after deductions for sales expense and income tax, when cull potatoes are available at 25 cents per hundredweight.

Table 4 shows the price that the manufacturer can pay for cull potatoes and realize 15 per cent net profit on fixed investment after payment of sales expense and income tax.

From table 3 it is apparent that corn must sell at $2.00 a bushel to enable a potato feed manufacturer to make a reasonable profit, 14 per cent, on his fixed investment. This presupposes that he must pay 25 cents per hundredweight for cull potatoes delivered to the plant. If corn should sell for $3.00 a bushel, his profit would be 53 per cent.

TABLE 3.

When Corn Sells at	Corn or Potato Feed is Worth	Profit Based on Fixed Investment*
$/Bus.	$/Ton	Per cent
1.75	62.48	4.1
2.00	71.40	14.0
2.25	80.33	23.9
2.50	89.25	33.7
2.75	98.18	43.6
3.00	107.10	53.4

* When cull potatoes are available at 25 cents per cwt.

TABLE 4.

When Corn Sells at	Corn or Potato Feed is Worth	Manufacturer Can Pay for Cull Potatoes*	
$/Bu.	$/Ton	$/Ton	$/Cwt.
1.50	53.55	1.11	.056
1.75	62.48	2.96	.148
2.00	71.40	4.81	.241
2.25	80.33	6.66	.333
2.50	89.25	8.51	.426
2.75	98.18	10.36	.518
3.00	107.10	12.21	.611

*Based on 15 per cent profit on fixed investment after payment of sales expense and income tax.

If the manufacture of potato feed is an enterprise owned by potato growers, they could sell cull potatoes for prices shown in table 4, corresponding to the current corn price, and also obtain 15 per cent return on the factory fixed investment. For example, an increase in the price of corn from $2.00 to $3.00 a bushel would increase the value of culls from 24 cents to 61 cents a hundredweight.

It should be emphasized that the data shown in tables 1, 2, 3 and 4 are based on a factory that will make potato feed 24 hours a day, 6 days a week, for 8 months each year from potatoes having a moisture content of 80 per cent. It will also dry other materials during 2½ months each year. It is assumed in tables 3 and 4 that potato feed is equal to corn in feeding value.

Usually, it is difficult to sell a new feedstuff at a price justified by its feeding value. Potato feed is a good example of this. It has been established by large-scale duck feeding experiments (4) that potato feed can be substituted for corn meal to approximately 20 per cent of the ration. The average price paid by New York State farmers June 15, 1951, for corn meal (5) was $4.25 per hundredweight, or $85 per ton. Obviously, potato feed should have been of equal value for feeding ducks. However, a recent survey made on Long Island, New York, where both potatoes

and ducks are plentiful, showed that potato feed could not be sold for that price. It was reported that a large feed mixing plant paid only $40 per ton for air-dried potato slices. This material, when ground, is equal to corn meal for feeding ducks (4). It is obvious that in addition to technical "know how," a good merchandising program is required to make the artificial drying of potatoes for feed profitable.

In many potato growing areas, it is not feasible to store potatoes for 8 months. In order to make potato feed profitably in these areas, by the method described, potatoes could be dried in available direct-fired, rotary driers used chiefly for some other purpose. For example, a drier used in the summer for drying alfalfa, could be used with auxiliary equipment for drying ground potatoes after the alfalfa season. By distributing some of the costs over a longer operating period, it is reasonable to expect that both the cost of drying alfalfa and the cost of making potato feed would be reduced considerably.

Summary

A practical method has been developed for making potato feed with a direct-fired, rotary, alfalfa-type drier.

A plant processing 62 tons of potatoes daily would produce about 13.8 tons of feed, at a cost of about $30.09 per ton. This plant would cost about $92,500. If cull potatoes are available at 25 cents per hundredweight, the cost to make a ton of product would be about $52.59. Based on the assumption that dried potatoes are equal to corn in feeding value, if corn sells at $2.25 per bushel, a Maine potato feed manufacturer might realize a profit of approximately 24 per cent on his fixed investment after payment of sales expense and income tax. These estimates are based on 8 months' operation on potatoes and 2½ months on drying other crops or vegetable field wastes.

Since potato feed is a relatively new commodity, a good sales promotion program will be required to enable it to compete with corn.

Potato feed should be made more profitably in areas where there are established drying plants, *i.e.*, alfalfa dehydrators, by operating in conjunction with them.

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RELATION OF WATER SUPPLY TO XYLEM DISCOLORATION OF POTATO TUBERS CAUSED BY VINE KILLING[1]

WM. G. HOYMAN[2]

A discoloration of potato tubers was observed in North Dakota in 1946 (11) following the killing of the vines by chemicals and mechanical methods. Other workers (1, 2, 3, 4, 5, 6, 16, 18, 19, 20, 22, 23, 24, 25, 26) and the author (12, 13) have reported this abnormality at various places throughout the United States and Canada where potato vines were eliminated before harvesting.

The most prevalent symptom consisted of a brown discoloration of the xylem. In some instances the adjacent parenchyma was also discolored. The extent of the affection within tubers varied but was generally confined to the stem end. Among the various forms of internal tuber discoloration described in the literature that might be confused with this injury are stem-end browning caused by *Fusarium* species, the vascular discoloration resulting from verticillium wilt, and frost necrosis of the ring type (14, 15). Edson (7) regarded some of the stem-end browning of vascular tissue as physiological, even in cases in which it extended well into the tubers. The stem-end browning and internal mahogany browning reported from Maine (8, 10) and the physiological internal necrosis that occurs in Wisconsin (17) are quite distinct from the discoloration following vine killing.

It is known that the amount of tuber discoloration is affected by the rapidity of vine killing and the stage of vine maturity. Most workers (2, 3, 4, 6, 11, 12, 18, 19, 20, 24, 25) agree that a positive correlation exists between the rapidity of killing and the amount of discoloration but a report from Maine (23) indicated no correlation. More discoloration generally occurs (2, 11, 12, 13) when the vines are killed early but some workers (3, 4, 6, 20) reported more injury when the plants approach maturity. In one instance (5) the date of killing was of no significance.

These conflicting reports may be due to the fact that certain climatic conditions have a bearing on the amount of discoloration. According to Goss (9), high temperature and low soil moisture often cause a vascular discoloration of tubers in Nebraska in the absence of any causal organism. In Iowa, Peterson and Gwinn (22) had an opportunity to compare the vine killing discoloration obtained during the hot, dry summer of 1949 with the results obtained the following summer when temperatures were below and rainfall above normal. They reported vascular discoloration in 1949 but not under the conditions that prevailed in 1950. Since vine killing practices have become established in North Dakota, tuber discoloration has not occurred to any great extent except in 1946. There was a deficiency of rainfall that year, especially just previous to vine killing. Rich (24) stated that vine killing discoloration occurs more

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frequently in Washington and British Columbia than in eastern states and eastern Canada. Hoyman (12, 13) and Kunkel *et al.* (16) have evidence from vine killing field experiments that drought affects the amount of discoloration. These results have been confirmed in greenhouse tests by Callbeck (4), but Meadows (20) and the author were not able to obtain discolored tubers in greenhouse pot experiments where soil moisture was varied. Murphy (21) studied the effects of drought on potato tubers and listed 10 abnormalities that occurred in Ireland during the dry summer of 1933. Among these were drought and heat necrosis characterized by the death of the vascular ring and surrounding parenchyma which turned golden yellow and later brown. In a recent report (27) from Great Britain on potato haulm destruction, it was indicated that the vine killing discoloration reported from North America had never been observed there.

Experiments were conducted at Fargo, North Dakota, from 1947 through 1951 to determine whether the amount of water supply during the growing season and the stage of vine maturity affected the amount of discoloration in tubers harvested from vines killed by chemicals or removed by cutting near the soil level.

Experimental Procedure and Results

During the 5 years these experiments were in progress, the soil moisture supply was varied by growing the potatoes under the following conditions: 1) with natural rainfall, 2) with natural rainfall plus irrigation, 3) on elevated soil with natural rainfall, and 4) in one year on elevated soil with natural rainfall but with the soil covered with roofing paper. The plot was located at the North Dakota Agricultural Experiment Station at Fargo, North Dakota, where the Fargo clay has a high capacity to furnish water to plants. During periods when there was a lack of sufficient precipitation for normal growth, certain rows were irrigated.

In order to provide conditions where the soil would have less moisture than normal, a bulldozer was used to make 6 elevated rows 18 to 24 inches high, 5 feet wide at the base and 50 feet in length. The elevated plantings for 1947 and 1948 were made on these rows but for the 3 remaining years they were made on 3 rows 5 feet high, 10 feet wide at the base and 80 feet long. The assigned tract was 120 by 144 feet and the north half of this area was occupied by the elevated rows constructed from the surface soil in this portion of the plot. The limited size of the plot did not permit the desired replications and statistical analysis of the results.

The certified Triumph seed used for this experiment was obtained from foundation seed growers in the western part of North Dakota. Although it was infected with virus X, it was free from other pathogens. Except in 1947, when the planting was delayed until June 15, the seed was planted during May. Partial control of the common potato insects was obtained by using DDT dust. Fusarium and verticillium wilts were not present in the plot and the vines were killed each year before the first killing frost.

The dates of irrigation and vine killing are given in table 2. At the first dates of vine killing, the vines showed little, if any, signs of maturity. They were maturing at later killing dates but never to the extent that they were brown. Approximately 2 weeks after the vines were killed, the tubers were harvested and examined for discoloration. Because slight

TABLE 1.—*Monthly precipitation in inches and departure from normal at Fargo, North Dakota, during the growing seasons of 1947 through 1951.*

Month	40-yr. Mean	1947	1948	1949	1950	1951
May	2.89	—1.56	—1.84	+0.65	+2.10	—1.26
June	4.05	—0.82	+0.52	—1.34	—1.76	—1.69
July	3.43	—2.63	+0.67	+1.52	—3.01	+0.34
Aug.	2.89	—0.40	—2.10	—1.70	—2.47	+2.75
Sept.	2.22	+0.06	—1.37	—1.86	—0.68	—1.43
Total	15.48	—5.35	—4.12	—2.73	—5.82	—1.29

stem-end discolorations may be caused by unknown factors, slightly discolored tubers were not regarded as being affected by the vine killing. If the discoloration extended a half inch or more from the place of stolon attachment, the vine killing symptom was more easily recognized (Fig. 1) and recorded. A more characteristic symptom of this abnormality may be observed by peeling a severely affected tuber so that the discoloration pattern shown in figure 2 will be evident. The author examined all 13,007 tubers included in the experiment in order to avoid any inconsistency in the manner the readings were made. In each of the 5 years the xylem discoloration was mostly confined to the stem end and seldom extended more than half the length of a tuber. Sometimes some of the vessels of a bundle were not discolored. Figure 3 shows a photomicrograph of an affected vessel.

Fig. 1.—Stem-end discoloration.

TABLE 2.—*The relation of water supply and time of vine killing on tuber discoloration, 1947 through 1951.*

Year and Row No.	Row Treatment	Date Irrigated	Method of Vine Killing	Date of Killing	Tubers Examined	
					Number	Per cent Discolored
1947, 1	Elevated		KCNO[1]	9/1	92	56.5
2	"		"	9/16	85	10.5
3	Elev. and covered		"	9/1	103	65.0
4	"		"	9/16	87	20.6
5	Normal		"	9/1	115	9.5
6	"		"	9/16	107	1.8
7	Irrigated	7/28, 8/7, 8/18, 8/29	"	9/1	89	6.7
8	"	"	"	9/16	131	1.5
1948, 1	Elevated		Cutting	8/21	140	3.5
2	"		"	"	92	3.2
3	"		"	"	90	1.1
4	"		KCNO[1]	"	104	2.8
5	"		"	"	106	5.6
6	"		"	"	85	3.5
7	Normal		"	"	104	3.8
8	"		"	"	122	4.9
9	"		"	"	73	5.0
10	Irrigated	7/20, 8/10, 8/21	"	"	116	0.8
11	"	"	"	"	118	0.8
12	"	"	"	"	124	0.8
1949, 1	Elevated		Cutting	8/16	157	15.2
2	"		"	8/26	171	42.6
3	"		"	9/6	176	23.8
4	Normal		"	8/16	292	18.1
5	"		"	8/26	433	15.0
6	"		"	9/6	437	17.8
7	Irrigated	8/13	"	8/16	231	9.4
8	"	"	"	8/26	313	3.5
9	"	"	"	9/6	420	9.7
1950, 1	Elevated		Cutting	8/13	167	4.1[2]
2	"		"	8/25	240	40.4
3	"		"	9/16	221	9.0
4	Normal		Not cut		236	1.2
5	"		"		291	2.0
6	"		"		253	3.5
7	"		Cutting	8/13	264	2.6[2]
8	"		"	8/25	355	34.3
9	Normal		"	9/16	273	5.4
10	Irrigated	8/7	"	8/13	214	2.8[2]
11	"	8/7, 8/24	"	8/25	384	6.7
12	"	"	"	9/16	290	5.5
1951, 1	Elevated,		Cutting	8/11	419	58.4
2	"		"	8/29	406	28.5
3	"		"	9/17	468	39.9
4	Normal		Not cut		408	9.8
5	"		"		469	7.4
6	"		Cutting	8/11	444	6.3
7	"		"	8/29	464	3.8
8	"		"	9/17	532	9.0
9	Irrigated	7/24	"	8/11	399	8.2
10	"	"	"	8/29	503	6.9
11	"	"	"	9/17	594	6.3

[1] Potassium cyanate used at a concentration of 50 pounds per 100 gallons of water and applied until the foliage was thoroughly wet.
[2] Four inches of new vine growth when dug.

Since physiological internal necrosis of potato (17) is more prevalent during seasons when temperatures are above normal, and drought and heat necrosis (21) occur under hot and dry conditions, soil temperatures in the differently-treated rows were recorded at various times during the course of the experiment. The readings were taken 8 to 10 inches below the soil surface. Since there was never more than 2°F. difference between the highest and the lowest temperature at any time the readings were made, soil temperature was considered to be of no significance in this experiment.

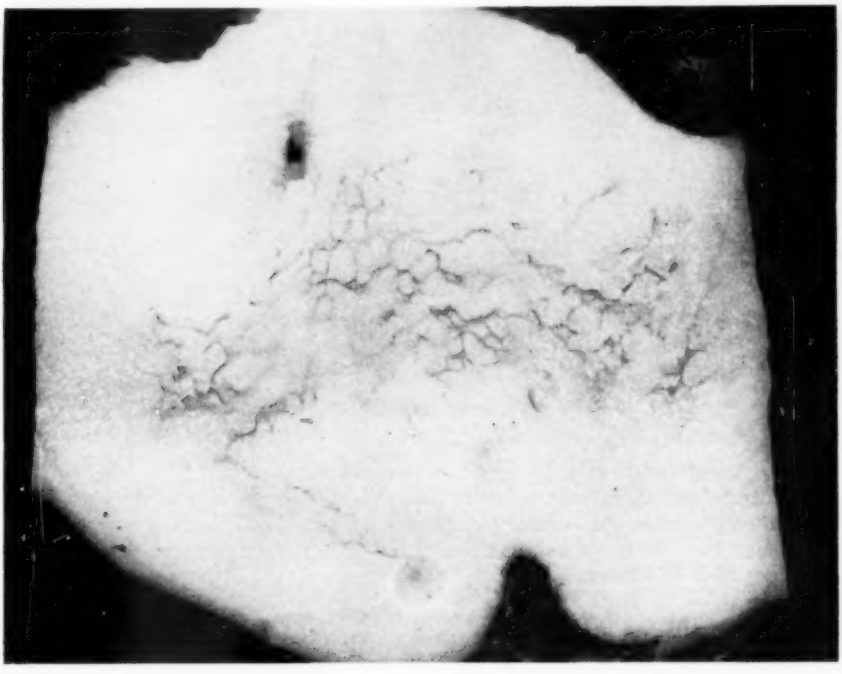

Fig. 2.—Discoloration pattern obtained upon peeling an affected tuber.

No attempt was made to correlate the amount of soil moisture with tuber discoloration. Soil moisture determinations were made at 10-day intervals during one of the 5 summers, but they were discontinued in favor of precipitation data. Potato growers can make their own field observations with respect to moisture or obtain precipitation reports from their nearest weather station. Very few farmers would make soil moisture determinations. It was, therefore, thought advisable to study the relation of water supply to discoloration.

The 40-year mean precipitation data and the monthly departures for 1947 through 1951 given in table 1 were obtained from daily records provided by the United States Department of Commerce, Weather Bureau Station, Hector Airport, Fargo, North Dakota. This station is one-half mile north of the plot. A deficiency of precipitation at certain periods

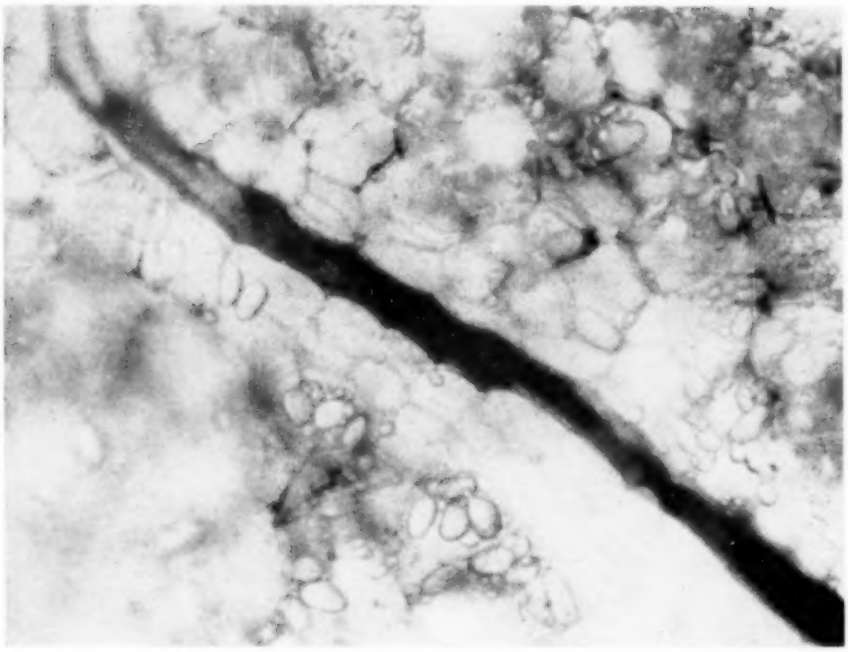

Fig. 3.—Photomicrograph of discolored xylem vessel.

provided ideal conditions to test the hypothesis that drought previous to vine killing increases the amount of xylem discoloration. It was also possible to compare the results obtained when the precipitation approached the normal or was in excess of normal. In 1951, for example, August had an excess of 2.75 inches.

The 1947 plot was planted June 15 and the vines in rows 1, 3, 5 and 7 were killed with a rapid vine killer, potassium cyanate, September 1. At this date the vines had not shown any signs of maturity. There was a departure of —5.35 inches in precipitation for the 5-month period and most of this had occurred before August. August lacked only 0.40 inch of rain, 0.63 inch being recorded on the last day of the month, the day before the first vines were killed. A low percentage of discoloration was present in tubers harvested from normal and irrigated rows (5 and 7) but over one-half the tubers from elevated rows 1 and 3 were injured. Much less discoloration was present in tubers harvested from vines killed September 16 but the percentage of injury from the various treatments remained in the same order as for the earlier killing. The irrigated rows had the least injury after both dates of killing.

A departure of —4.12 inches in precipitation occurred during the growing season of 1948 and 2.10 inches of this deficiency occurred during August. There was more than the normal precipitation in June and July. All the vines were killed August 21, or 90 days after planting. A low percentage of discoloration was obtained this year but the results were

consistent in that the least amount of injury occurred in tubers harvested from irrigated rows.

The 1949 plot was planted May 14 and the treatments consisted of elevated, normal and irrigated rows. For July there was a departure of +1.52 inches but August lacked 1.70 inches when compared with the 40-year mean. The only precipitation from July 28 to August 16, the day the vines in rows 1, 4 and 7 were killed, was 0.04 inch July 31 and 0.26 inch August 15. The expected discoloration was obtained in tubers from the elevated and normal rows, but the greater injury anticipated in row 1 than in row 2 did not develop. Approximately 3 times as much injury was present in elevated row 2 in which the vines were killed 10 days later. The tubers from the irrigated rows had the least discoloration.

From the precipitation data in table 1 for 1950, a high percentage of tuber discoloration would be expected. The largest departure (−5.82 inches) from normal occurred that year and July and August each had only 0.42 inch of rainfall. The 1950 plot was planted May 30 and the vines in rows 1, 7 and 10 were cut August 13, or 75 days later. When these 3 rows were harvested 2 weeks later there was approximately 4 inches of new vine growth. The low percentage of discoloration in the tubers from these 3 rows may be explained by the fact that the plants were not killed by cutting the vines at the soil level.

With the exception of irrigated row 11, the tubers harvested from vines killed August 25 had a high percentage of injury and those from the 3 rows killed later (September 16) had the expected low percentage of discoloration.

Another treatment of the vines was included in the 1950 experiment in order to learn more about the discoloration process. The vines on rows 4, 5 and 6 were allowed to grow until the tubers were harvested. The plants in row 4 were of normal green color when harvested on the same date (August 27) as rows 1, 7 and 10, but there was only 1.2 per cent discoloration. Row 5 was harvested at the same time as rows 2, 8 and 11 and row 6 on the same date as rows 3, 9 and 12. The very small amount of discoloration from these 3 uncut rows suggested that the sudden separation of tubers from the plants interfered with the discoloration process. The results from rows 5 and 8 were especially interesting. These rows were harvested September 8 and the row with vines intact showed only 2.0 per cent injury compared with 34.3 per cent in the row where the vines had been cut. Pulling up of the vines and roots would be a somewhat similar treatment. Meadows (20) reported that this practice was the only method which was effective from the standpoint of avoiding vascular discoloration.

The treatments in the 1951 plot were similar to those of the previous year. The precipitation more nearly approached the 40-year mean than in other years during the experiment. July had a departure of +0.34 inch and August an excess of 2.75 inches. The most precipitation during any 24-hour period in August was 1.53 inches on the first day of the month. From August 1 to the first date of vine killing on August 11, 2.08 inches had been recorded. Considerable discoloration occurred in each of the elevated rows but the amount of injury in the other rows was low and approximately the same.

Discussion

The results show that the amount of water supply previous to vine killing and the time of killing are factors causing xylem discoloration, and the data from the normally-treated rows should be of significance in predicting the occurrence of this injury. The precipitation for August is probably more important than for any other month and the amount of previous precipitation should also be considered. Another factor is the capacity of the soil to furnish water to plants. The years 1948, 1949 and 1950 each had a considerable deficiency of precipitation during August. The expected vine killing discoloration was not obtained from the normal rows in 1948, when a deficiency of 2.10 inches occurred in August. In 1949, the tubers harvested from the normal rows had the expected discoloration, ranging from 15.0 to 18.1 per cent. In 1950, very little injury occurred in tubers harvested from the normal row (No. 7) on which the vines were cut August 13. Removal of the vines at this early date did not cause the death of the remaining plants and new vine growth was present when the tubers were harvested. Vine removal August 25 caused 34.3 per cent tuber discoloration in row 8, but when the vines were cut 22 days later in row 9 the injury was only 5.4 per cent.

In contrast with the 3 years in which there was a moisture deficiency in August, the data in table 1 show that the precipitation for this month in 1947 was approximately normal and departed +2.75 inches in 1951. If August precipitation is an important factor in predicting vine killing discoloration, the years 1947 and 1951 provided an opportunity to compare the effect with the 3 moisture deficient years. In 1947, the vines in normal row 5 were killed September 1 and a low percentage of the tubers were discolored. Very little injury was present in tubers harvested from the other normal row on which the vines were killed 15 days later. A low percentage of vine killing discoloration would be expected in a year such as 1951 and the data from rows 6, 7 and 8 show that this was the case.

To support the hypothesis that low soil moisture is an important factor causing vine killing discoloration, reference should be made to the results obtained from the elevated and irrigated rows. Except for 1948 and row 1 in 1950 with new vine growth, discoloration in the elevated rows was consistently greater than that in the normal rows. The most injury during the 5 years was 65.0 per cent in row 3 in 1947. This elevated row was covered with roofing paper to prevent the rain from being absorbed by the soil near the plants. The lowest percentage of discoloration was obtained in tubers harvested from the irrigated rows. According to the results from this experiment, vine killing discoloration should not be of much concern when irrigation is practiced properly.

In most instances early vine killing caused the largest percentage of discoloration. In each of the 4 row treatments in 1947 considerably more injury was present in tubers harvested from the vines killed September 1 than from those killed 15 days later. In 1948, all the vines were killed on the same date. The +1.52 inches of July rainfall in 1949 may have affected the amount of discoloration obtained in tubers harvested from vines killed August 16. In elevated row 1 the injury was approximately one-third as much as in the elevated row killed 10 days later. Early killing was of little significance in the amount of discoloration obtained in the normal

and irrigated rows. With the exception of rows 1, 7 and 10, which had new vine growth, the expected results were obtained from the 1950 vine killing experiment. In 1951, the percentages of discoloration were low in all except the elevated rows, and over one-half the tubers were injured in the elevated row killed first.

Summary

1. In order to determine the relation of water supply to vine killing discoloration, Triumph potatoes were grown under the following conditions: 1) with natural rainfall, 2) with natural rainfall plus irrigation, 3) on elevated soil with natural rainfall, and 4) in one year on elevated soil with natural rainfall but with the soil covered with roofing paper.
2. The treatment producing the most xylem discoloration was elevating the soil and covering it with roofing paper. This was followed by elevating the soil but leaving it uncovered.
3. The years 1948, 1949 and 1950 each had a deficiency of rainfall during August and with the exception of 1948 the expected tuber discoloration was obtained in the normally-treated rows.
4. In 1947 the August rainfall was approximately normal and a departure of +2.75 inches occurred during this month in 1951. The expected low percentage of discoloration was found in the normally-treated rows during each of these years.
5. A low percentage of discoloration occurred in the tubers harvested from the irrigated rows and from the rows where the vines remained until harvest.
6. In most instances, early vine killing caused the most discoloration.

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TUBER SYMPTOMS OF CALICO[1]

C. M. SLAGG[2]

Calico, caused by *Marmor medicaginis* var. *solani*, is well known as a conspicuous but minor disease of potatoes. As indicated by its binomial nomenclature the virus causes a similar disease of alfalfa. On potato foliage this disease causes strikingly bright yellow to clear white areas on the leaves, the clear white blotching usually occurring on the more shaded portions of the foliage.

In western Nebraska this disease is more prevalent in proximity to fields of alfalfa, and is much more evident in irrigated areas where potatoes and alfalfa are alternated in the crop rotations practiced. A rather high proportion of calicoed plants may often be seen in fields bearing the first crop of potatoes after several years in alfalfa.

Foliage symptoms include more or less stunting of vine growth, varying from no noticeable lessening of foliage growth, and few chlorotic areas, to extreme dwarfing and yellowing. Severely affected hills resemble curly dwarf, except for the calicoed leaves. Field observations for a number of years in western Nebraska, and field and greenhouse tests at Manhattan,

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Fig. 1—Symptoms of calico on potato tubers. Three diseased tubers and one disease-free (lower left). Note cracking and corking at bud end, with colorless sector on upper right tuber. Abnormal flattening present but not shown in this illustration.

Kansas, indicate that tuber perpetuated virus is responsible for the extreme dwarfing symptoms.

A complex of tuber symptoms, not previously described in articles seen by the author, has been found associated with calicoed foliage. These tuber symptoms, illustrated in figure 1, although not uniformly present, can usually be seen on from one to several tubers in lightly infected hills, and on a majority of the tubers produced by severely affected plants. These tuber symptoms of calico in potatoes may be listed as follows:

1. Reduction in size. Tubers from calico plants are smaller, the amount of dwarfing increasing with the severity of the disease.
2. Reduction in length of tuber, so that it appears abnormally flattened.
3. Gnarling or distortion of bud end of tuber.
4. Cracking of bud end of tuber.
5. Corking of bud end of tuber.
6. Variegation. Lighter bands or sectors are occasionally seen in varieties having colored tubers.

Of the tuber symptoms of calico above listed, those most commonly present are dwarfing, flattening, and gnarling or distortion of the bud end.

The usually low incidence of tuber-perpetuated calico in the field may be partially explained by the fact that dwarfed and misshapen calico tubers are probably largely discarded in sorting and grading. Also, where roguing of seed fields is done, the conspicuous variegated calico hills are easily eliminated.

DATURA FEROX: A TEST PLANT FOR POTATO VIRUS Y[1]

J. E. VAN DER PLANK AND C. F. O'CONNOR[2]

Common *Datura stramonium* (Jimson weed) is immune from potato virus Y. But *D. ferox* is susceptible and fills the need for a convenient, simple test for the virus both in the foliage and in the tubers.

Symptoms are very clear and characteristic. They appear about 12 days after inoculation, first as a clearing of the veins and then as a marked puckering, crumpling and distortion of the young leaves. These symptoms are remarkably constant. Strains of virus Y that give widely different reactions in potato are difficult to distinguish in *D. ferox*, and no strain could be found so mild that it is carried without clear symptoms in *D. ferox*. Potato virus C, a variant of Y, behaves like Y itself.

Transmission occurs readily. When foliage is being tested, the sap is expressed in the usual way. In testing tubers, the skin is cleaned and a small patch rubbed off with coarse sand-paper. The wet abraded surface is then wiped over leaves of *D. ferox* that have been dusted with carborundum. With fresh turgid tubers the release of sap is enough to give an adequately wet surface, but a drop of water or buffer solution may be used if it is needed. The leaves are then rinsed in the usual way.

D. ferox is also susceptible to potato virus *x*. The symptoms are like those in *D. stramonium* or *D. tatula* which are too well known to need description. The main difference is that symptoms in *D. ferox* are a little more severe, and fewer strains of virus *x* are carried without symptoms. Generally, the presence of virus *x* does not greatly interfere with tests for virus Y, unless the strain of virus X is very severe or lethal. To test for virus Y in the presence of strains of virus X lethal to Datura, the test plants should be inoculated 5 to 7 days beforehand with a mild strain of virus X.

Nowadays, as the advantage of growing potatoes free from latent mosaic is becoming more apparent, the mass testing of foundation seed for virus X is becoming quite a common practice. Those who have been using *D. stramonium* or *D. tatula* for this purpose would find it better to use *D. ferox* instead and by so doing test for both virus X and virus Y in one operation.

D. ferox is also susceptible to potato virus A by sap inoculation. But there is no possibility of confusing symptoms of viruses A and Y. Those of virus A are free from the puckering and distortion of the leaves, and take much longer to develop.

D. ferox has a similar growth habit to *D. stramonium* and *D. tatula*, and shares with them those characteristics which have made these species so popular as test plants for plant viruses. *D. metel* (from two sources) and *D. metcloides* (from a single source) were also tested and found to

be susceptible to virus Y. They could possibly be used in place of *D. ferox*, but this has not been investigated in detail.

[1] Accepted for publication November 30, 1951.
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ERRATA

In the April 1952 issue in the article entitled "The Certification of Potatoes for Seed in Canada," in the fourth paragraph on page 87, the genus name of the flea beetle should be "*Disonycha*." In the eighth paragraph, line 1 should read "45 varieties" instead of "41 varieties."

In the same issue in the article entitled, "Effect of Thiourea on the Number of Stems on the Tuber Set and on the Yield of Katahdin, Kennebec and Sebago Potatoes," the word 'longer" on line 5, page 94 should read, "larger."

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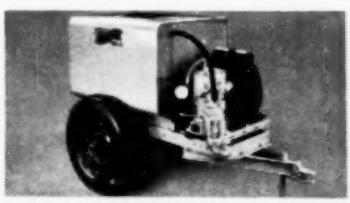

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